

Orientation changes upon attachment of spider hairs investigated *in situ* using scanning X-ray nanobeam diffraction and small-angle scattering

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The hairy attachment system of spiders enables these animals to walk upside-down on plants, walls, on rough and smooth surfaces, and support a multiple of the body weight without the use of glue. These outstanding biological structures comprise of pads including hundreds to thousands of specially designed hairs that are made of composite materials consisting of proteins and reinforcing chitin fibers (Fig. 1). The goal of our study was to gain an in-depth understanding of the working principle of the attachment and detachment processes of single hairs to a surface, which is likely based on the structurally determined material properties of the contact elements at the tips of the hairs. The accompanying changes of the shape of the contact elements and their self-orientation in parallel with a surface lead to the establishment of van der Waals forces between the hair tips and the substrate crucial for attachment.

Scanning X-ray nanobeam diffraction and small-angle scattering are ideal tools to reveal the structure and orientation of the smallest attachment hairs. Moreover, they can be combined with an *in situ* attachment/detachment procedure. The experiments were performed at the nanobeam of beamline ID13 (ESRF, Grenoble, France) with a beam size of $100 \times 100 \text{ nm}^2$ and an energy of 14.9 keV. The tips of single adhesive hairs of the spider *Cupiennius salei* were scanned in a combined WAXS/SAXS configuration in fine detail with a resolution of 250 nm. A piezo-driven actuator was used to move the hairs relative to a thin silicon nitride window in order to attach and detach them, respectively.

Maps of the WAXS and SAXS signals allow for a detailed analysis of single contact elements (Fig. 2). Taking the dimensions of the structures with a width of about $1 \mu\text{m}$ and a thickness of less than 100 nm into account, this result is remarkable. The SAXS signals reflect the fiber orientation. Changes upon hair attachment concern those orientation aspects of the thinnest structures. Oriented WAXS signals of chitin (fiber diffraction patterns) are only found in the hair shaft $50 \mu\text{m}$ away from the tip. At the tip, amorphous rings are measured. This finding points to a complex structural embedding of the chitin fibrils in the protein matrix and to relatively small chitin aggregates. — Our results will help to improve artificial attachment devices.

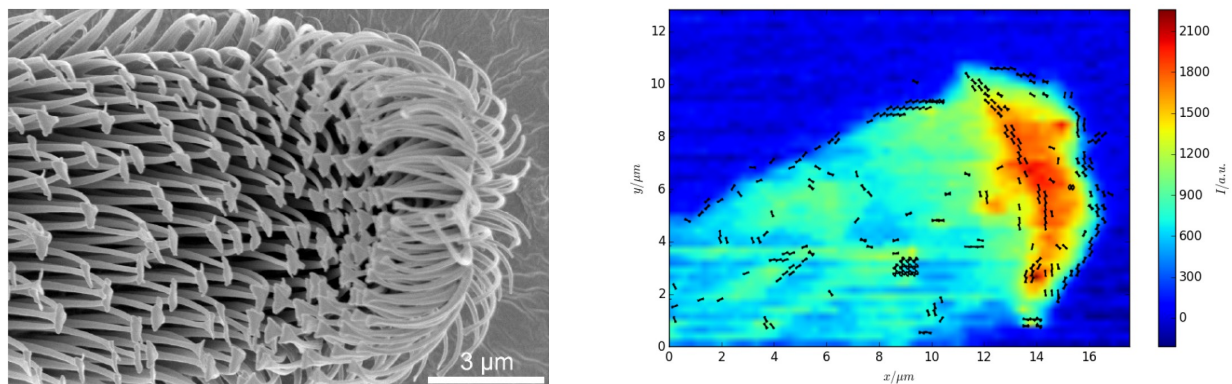


Fig. 1 (left): SEM image of the tip of a spider attachment hair; the spatulae making the contact to a surface can clearly be seen. **Fig. 2** (right): combined map of WAXS intensities (diffuse ring; color scale) and SAXS orientation (black lines) of an attached spider hair.